Pine Thinning and Spacing

Moderator:

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ECONOMIC RATIONALE FOR PLANTING LESS TREES IN THE FACE OF SEEDLING MORTALITY

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Abstract—Simple economic analyses are used to demonstrate that planting extra trees to compensate for initial seedling mortality can actually reduce the profit expected from a pine plantation. At a 6-percent interest rate, the cost of planting 15 or 25 percent additional seedlings compounded to the end of a 30-year rotation exceeds the revenue lost to these rates of seedling mortality when the initial target density is 700 and 800 seedlings per acre, respectively. At 8 and 10-percent interest rates, the compounded costs of the additional seedlings always exceed the revenue lost to seedling mortality. Comparing the marginal costs and benefits of increments of 50 seedlings indicate that optimal planting density decreases in the face of severe seedling mortality. Seedling mortality represents an inefficiency in a forest production system, and unless establishment efficiency can be improved, planting costs will have to be reduced to maximize profitability.

INTRODUCTION

Planting trees plays an important role in the structural development of a stand and its eventual profitability. Much energy has been expended in conducting spacing trials and economic analyses to determine optimal initial spacing (Bennett 1959, Bowling 1987, Caulfied and others 1992, Land and others 1991, Taylor and Fortson 1991). This initial planting density is typically supplemented to compensate for the number of seedlings that experience has shown to die during the first growing season. This practice can actually undermine the initial planning effort and potential profitability of the rotation.

Planting “extra” trees to compensate for initial seedling mortality undermines the initial planning effort by affecting the initial planting costs and potential revenues at the end of the rotation. Seedling costs should be based on costs per established seedling; planting additional seedlings, regardless of initial mortality, will increase cost. Revenue at the end of rotation is a function of rotation length, site quality, and overall stand density throughout the rotation; additional seedlings change stand density. Studies show that trees grow in relation to proximity and size of neighboring trees (Stiell 1978 and 1982). Consequently, when additional trees are planted, the majority of the plantation is overstocked relative to management objectives. The increased density reduces average diameter growth and the number of trees in the more valuable product classes.

The objective of this paper is to demonstrate that initial planting density should not be changed when only light to moderate seedling mortality is expected and that fewer, not greater, numbers of trees should be planted when severe seedling mortality is expected. These outcomes will be demonstrated for loblolly pine (*Pinus taeda* L.) in the western Gulf region and will be supported by two simple approaches: (1) comparisons of costs and revenues and (2) analysis of marginal costs and marginal benefits of tree planting

METHODS

Seedlings were assumed to cost \$0.05 and \$0.07 to plant (Dubois and others 1999), and seedling and planting costs were compounded at 6 percent per year to the end of a 30-year rotation. Revenue at the end of the rotation was calculated with the program COMPUTE_MERCHLOB (MERCHLOB for short) (Busby and others 1990). This program projects growth and yield for loblolly pine plantations in the western Gulf area and then calculates the product mix that produces the greatest revenue based on product specifications and prices. Products considered in this demonstration include pulpwood, chip and saw, and sawtimber with unit prices of \$26.00/cord, \$90.00/cord, and \$400.00/MBF, respectively (table 1). Growth projections do not include thinning and were conducted with a site index of 65 feet at a base age of 25 years.

Table 2 presents the results of a simple comparisons between the variable costs of planting compounded to the end of the rotation and revenue loss resulting from mild and moderate seedling mortality rates of 15 and 25 percent, respectively. The compounded costs of planting 15 or 25 percent more seedlings are compared with the projected revenue lost with 15 or 25 percent less seedlings than planted at the beginning of the rotation. Gaps are created in the plantation when seedlings die, resulting in trees growing closer together than the overall number of seedlings would indicate. In this comparison no allowance was made in the growth and revenue projections for the variation in spacing caused by seedling mortality. In other

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words, spacing between surviving seedlings was considered uniform for all projections. This probably underestimates the growth lost to seedling mortality because average stand diameter would be larger with uniform spacing and thus, more valuable than trees in a stand with the same number of trees but with closer, overall spacing.

Marginal analysis is used to demonstrate the effect of seedling mortality on optimal planting density. Marginal analysis is based on the law of diminishing marginal returns and compares the additional cost of each increment step of input with the resulting incremental change in benefit. The optimum input level occurs when the incremental or marginal cost equals the marginal benefit. Dean and Chang (in press) detail the procedure for using marginal analysis to determine optimum planting density. For this analysis, marginal cost is the cost of additional established seedling lots of 50 compounded at 6 percent for 30 years, and marginal benefit is the change in revenue associated with each increase of 50 additional established seedlings. Seedling mortality transfers their cost to the surviving seedlings; therefore, the cost of seedling mortality is represented in this analysis by increasing the per seedling costs by either 15 or 25 percent. Revenues are calculated with MERCHLOB for rotations of 30 years with no thinning on sites with a site index of 65 ft at a base age of 25 years.

RESULTS

At a 6 percent annual interest rate, the cost of planting additional seedlings compounded to the end of the rotation is less than the projected revenue loss due to seedling mortality for planting densities less than 800 seedlings per acre (table 2). When the target planting density is 800 seedlings per acre, the expected revenues lost with mild and moderate seedling mortality rates are $30.20 and $97.53 per acre, respectively. The costs of planting 15 and 25 percent more than the target number of 800 seedlings per acre compounded at 6 percent to the end of the rotation exceed the respective revenue losses from seedling mortality by $57.40 and $48.47 per acre. At 8 and 10 percent interest rates, the costs for compensating for initial seedling mortality always exceed the expected revenue losses for the target planting densities investigated in this demonstration (table 2).

Marginal analysis of the costs and benefit of each 50 seedling increase in surviving density indicates that with

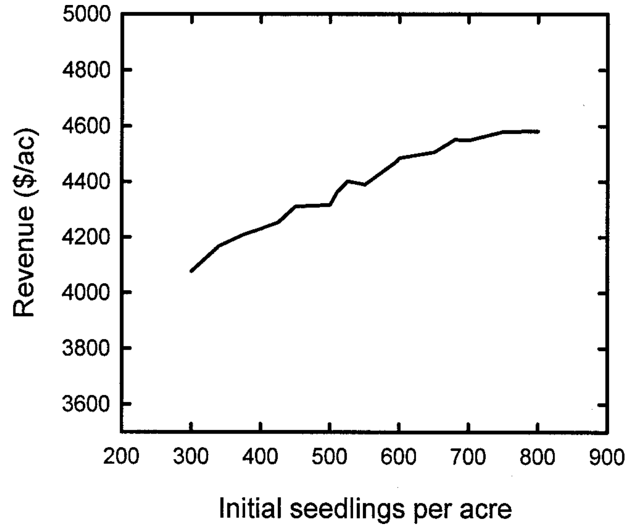

Figure 1—Revenue at the end of a 30-year rotation as projected by the growth-and-revenue simulator COMPUTE_MERCHLOB as a function of initial seedlings per acre for loblolly pine plantations with no thinning.

100 percent seedling survival and a 6 percent interest rate, the optimal number of established seedlings is 700 per acre because the additional revenue gained from having 750 surviving seedlings per acre over having 700 surviving seedlings per acre is $15.37/acre less than the cost of the additional seedlings (table 3). Marginal seedling costs increase $5.40/acre with mild initial seedling mortality, but the increase is not enough to affect the optimum planting density. The increased seedling cost of $9.07 associated with moderate seedling mortality is enough to affect optimum planting density. When 25 percent of the seedlings are expected to die, the marginal cost of each 50-seedling increase in surviving density is $45.37/acre which is greater than marginal benefit of each successive 50-seedling increase in surviving density greater than 600 seedlings per acre.

DISCUSSION AND CONCLUSION

According to MERCHLOB, projected revenue at the end of a 30-year rotation steadily (though not monotonically) increases as initial planting density increases from 300 to 800 seedlings per acre (figure 1). At the lower part of this range, planting additional seedlings to compensate for initial mortality actually increases revenue at a faster rate

Table 1—Product specifications and prices used in COMPUTE_MERCHLOB to calculate revenues (Dubois and others 1999)

Product Category	Price per unit	Minimum diameter	Maximum diameter
	$	inches	
Pulp wood	26.00/cord	3.5	12.0
Chip-and-saw	90.00/cord	6.0	12.0
Saw timber	400.00/MBF[a]	9.5	18.0

[a]MBF = 1,000 board feet Doyle scale

Table 2—Projected revenue lost in a loblolly plantation across a range of initial seedlings per acre (SPA) due to two rates of seedling mortality compared with the cost of planting additional seedlings to compensate for the mortality rate compounded for a 30-year rotation with various annual interest rates. Values are dollars per acre, and revenue projected with the growth-and-revenue generator COMPUTE_MERCHLOB.

	Seedling mortality rate							
	15 pct				25 pct			
	Revenue loss	Cost of additional seedlings			Revenue loss	Cost of additional seedlings		
SPA		6 pct	8 pct	10 pct		6 pct	8 pct	10 pct
	$/ac							
400	61.93	43.80	102.00	144.60	153.88	73.00	170.00	241.00
500	62.42	54.75	127.50	180.75	107.88	91.25	212.50	301.25
600	121.84	65.70	153.00	216.90	173.62	109.50	255.00	361.50
700	77.33	76.55	178.50	253.05	146.77	127.75	297.50	421.75
800	30.20	87.60	204.00	289.20	97.53	146.00	340.00	482.00

than costs escalate with a 6 percent interest rate. At the upper end of this range (and at the uppermost of the range for the moderate mortality rate), however, the associated costs of additional seedlings equal or exceed the additional revenue gained with the extra seedlings; the best outcome with a 6 percent interest rate is a wash. With 8 and 10 percent interest rates, the additional seedlings always cost more than the recovered revenue.

The simple comparisons of the cost of planting additional seedlings and the revenue that the additional is intended to recover at the end of the rotation is actually a form of marginal analysis. The main difference is that the simple comparisons are evaluating revenue recovered with the cost of compensating for seedling mortality, whereas, with comparison marginal analysis, the cost of an additional surviving seedling is compared with the additional revenue it produces. Since the costs of seedlings that die are assigned to the surviving seedlings, seedling mortality acts to increase marginal planting costs, which for moderate and worse mortality rates, results in lower planting densities. Increasing interest rates also result in lower planting densities that optimize profit.

Table 3—Marginal analysis of costs and benefits for planting additional seedling lots of 50 loblolly pine seedlings per acres (SPA). All values are dollars per acre. Revenue projected with COMPUTE_MERCHLOB with no thinning. Marginal costs calculated with an interest rate of 6 percent. Optimal planting density for each mortality rate designated with a (*).

SPA	Revenue	Marginal benefit	Marginal costs		
			0 pct mortality	15 pct mortality	25 pct mortality
		$/ac			
550	4390.06				
		95.19	36.30	41.70	45.37 (*)
600	4485.25				
		20.93	36.30	41.70	45.37
650	4506.18				
		42.94	36.30 (*)	41.70 (*)	45.37
700	4549.02				
		31.60	36.30	41.70	45.37
750	4580.62				
		2.16	36.30	41.70	45.37
800	4582.78				

Seedling mortality can be treated as a measure of inefficiency, and inefficiencies always increase costs relative to revenues, especially in an enterprise that requires decades to produce its product. This analysis demonstrates that in many cases, attempting to overcome establishment inefficiency with increased numbers of seedlings will reduce profitability. Until the establishment efficiency can be improved, input or planting costs need to be reduced to maximize profitability. Focusing on establishment efficiency, i.e., seedling survival, will probably be more beneficial to the enterprise than overplanting to compensate for seedling mortality. Many factors are known to increase initial seedling survival. These factors include prudent site preparation, correctly matching species with site, and following the recommended procedures for storing, transporting, handling, and planting seedlings. According to these analyses, the most profitable operation will be obtained by following the establishment prescription and maximizing establishment efficiency by properly executing each element of the plan.

REFERENCES

Bennett, F.A.; McGee, C.E.; Clutter, J.L. 1959. Yield of old-field slash pine plantations. Paper No. 107. Asheville: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experimental Station. 19 p.

Bowling, D. 1987. Twenty-year slash pine spacing study: what to optimize. In: Phillips, Douglas R., ed. Proceedings of the Fourth Biennial Southern Silviculture Research Conference; 1986 November 4-6; Atlanta. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 300-304.

Busby, R.L.; Ward, K.B; Baldwin, Jr, V.C. 1990. COMPUTE_MERCHLOB: a growth and yield prediction system with a merchandising optimizer for planted loblolly pine in the West Gulf region. Research Paper SO-255. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 22 p.

Caulfied, J.P.; South, D.B.; Somers, G.L. 1992. The price-size curve and planting density decisions. Southern Journal of Applied Forestry. 16(1): 24-29.

Dean, T.J.; S.J. Chang. in press. Using simple marginal analysis and density management diagrams for prescribing density management. Southern Journal of Applied Forestry.

Dubois, M. R.; McNabb, K.; Straka, T.J. 1999. Costs and cost trends for forestry practices in the South. Forest Landowners. 58: 3-8.

Land, S. B. Jr.; Belli, K. L.; Duzan, H. W. Jr. 1991. Family, spacing, and family-by-spacing effects on loblolly pine during five years after planting. In: Coleman, Sandra S. and Neary, Daniel G., eds. Proceedings of the Sixth Biennial Southern Silviculture Research Conference; 1990 October 30-November 1; Memphis. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 744-756.

Stiell, W. M. 1978. How uniformity of tree distribution affects stand growth. The Forestry Chronicle 54: 156-158.

Stiell, W. M. 1982. Growth of clumped vs. equally spaced trees. The Forestry Chronicle 58: 23-25.

Taylor, R.G.; Fortson, J.C. 1991. Optimum plantation planting density and rotation age based on financial risk and return. Forest Science. 37(3): 886-902.

LOBLOLLY PRUNING AND GROWTH CHARACTERISTICS AT DIFFERENT PLANTING SPACINGS

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Abstract—In 1990, an abandoned farm pasture located on the Calhoun Research Station, Calhoun, Louisiana was planted in loblolly pine (*Pinus taeda L.*) at five different spacings. The spacings were 12X6, 12X8, 10X6, 16X6 and 24X6. Variables measured were DBH, height, branch diameter, height to first branch and first branch whorl, fusiform occurrence, and forking. Ice damage after an initial thinning was evaluated. The wider spacings generally produced trees with the largest limbs and the shortest height to retained limbs. The higher density stands produced slightly taller but smaller DBH trees. Fusiform and forking were significant but not related to the spacing density. The two highest density stands (10X6 and 12X6) were greatly affected after thinning by the ice storm in 2001. Overall the 12X8 spacing was the best for growth, pruning and had minimal damage when exposed to ice.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is a fast growing conifer species with the ability to self-prune when growing in stands that have sufficiently dense competition. In stands that have lower planting densities the tendency is to retain limbs longer and produce larger limbs which leads to larger knot size and the production of lower lumber and plywood grades. The densities that produce the most desirable boles (knot free or small knots) do not optimize diameter growth and rapid production of high value saw and plywood logs. There is a fine line between planting density, natural pruning, sustained rapid growth, and yield of economically useable wood. An ideal spacing is one that profitably grows the smallest size usable tree (Smith and others 1997).

The question is, what is the optimum planting density that will maintain consistent growth rates and stimulate natural pruning, decreasing the number and size of limbs, and increasing the height to retained limbs? Also, initial spacing affects bole strength during early plantation development (Wiley and Zeibe 1991; Amateis and Burkhart 1996; Belanger and others 1996). Trees planted at wider initial spacings have slightly more taper are less likely to suffer the effect of strong winds and ice damage problems when thinned. The key to productive loblolly pine plantations is to maintain an acceptable growth rate and develop a strong central bole with enough intraspecific competition to facilitate natural pruning.

There is limited information on the development and loss of limbs at various spacings and the growth of the stands in diameter, height, and bole strength. A loblolly pine plantation planted at various spacings in north central Louisiana was used to evaluate the effect of various levels of competition on branching characteristics and tree growth.

METHODS

In February 1990, a loblolly pine plantation was established on the Calhoun Research Station, Louisiana Agricultural Experiment Station, Calhoun, Louisiana. The area had been part of a pasture and cattle management research program for several decades and was covered with bahiagrass, bermudagrass, and other forages. The soils are composed of approximately 50/50 Ora-Savannah and Ruston-Lucy associations. The Ora is a fine loamy, siliceous, semi active, thermic Typic Fragiudult, and the Savannah is a fine-loamy, siliceous, semi active, thermic Typic Fragiudult. The Ruston is a fine-loamy, siliceous, semi active, thermic Typic Paleudult, and the Lucy is a loamy, kaolinitic, thermic Arenic Kandiudult. These pastures had been limed and fertilized for forage production.

The site was originally planted to investigate straw production for the landscaping industry and the impact that the repeated removal of straw would have on the long-term site productivity. Five different planting densities were used to facilitate and evaluate the removal of the pine straw and the application of chicken litter as a fertilizer. They included 10X6, 12X6, 16X6, 24X6, and 12X8 foot spacing arrangements having initial seedling densities of 726, 605, 454, 302, and 454 seedlings/acre. These planting densities were duplicated over the 50-acre site. Planting stocks were

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commercially available, genetically improved seedlings and were machine planted. Herbaceous weed control in the row was done with a herbicide tank mixture of oust/ velpar.

In 1999, the stand was measured for natural pruning and growth characteristics. No fertilizer had been applied or straw removed prior to the initiation of the measurements. Four one-tenth acre plots were randomly selected and measured in each of the spacings. Measurements taken were height to the first limb stub, height to the first live limb, height to the first branch whorl, diameter of whorl limbs, DBH, total height, height to first fork, and occurrence of fusiform rust. The design was a completely randomized with five treatments. Analysis of variance was done to determine significance and Duncan's Multiple Range Test was conducted for means separation (SAS 1995).

RESULTS AND DISCUSSION

Limb Height Characteristics

The height from the ground to the first non-pruned dead limb was significant (P > 0.05)(table 1). The 10X6 had the greatest height (1.36 ft.) to the first dead branch and the 12X8 had the least (1.15 ft.). However, the difference between the largest and smallest mean was only 0.21 inches, which has little impact on stand development.

The height to the first live limb and first whorl were both significant (P<0.05). The emerging pattern was expected, and natural pruning was less on wider spaced (table 1). The height to the first live limb was greatest in the 12X6 (12.1 ft.) and the least was in the 24X6 (7.3 ft.). The height to the first whorl was similar with the 10X6 having the greatest height (14.8) and the 24X6 having the least height (9.9).

Branch and Stem Diameter

The size of the live branches was related to planting density, wider the spacing the greater the branch diameter (table 1). Branch diameter was significant (P<0.05) with a range from 0.70 for the 10X6 spacing to 0.94 for the 24X6 spacing, a considerable size difference for nine-year-old trees.

Total Height and DBH

Mean total height among planting densities differed significantly (P<0.05) (table 2). The widest spacing, 24X6, had the shortest trees (27 feet), which can be attributed to the lack of competition causing wide crown architecture and short trees. The 12X8 had the tallest trees with a mean height of 36 feet. The other three spacings were intermediate. These trees are only nine years old and, with the exception of the widest spacing, the spacings are becoming less variable over time and will probably reach an equality in height in a few years. This would follow the pattern described by Barnes and others (1998) on the use of height as an indicator of site and the use of height as the major component in site index determinations.

DBH differed significantly among planting densities (P<0.05)(table 2). Mean DBH on the 12X8 spacing exceeded all other planting densities with the 10X6 and 12X6 having the smaller DBH. Since diameter is sensitive to intraspecific competition, this was expected. However, DBH on the widest spacing (24X6) ranked third among treatments and was significantly smaller than the 16X6 DBH. The unusual competition pattern with competition rectangles of 6 feet on one side and 24 feet on the other may have influenced tree growth on the 24x6 spacing.

Fusiform, Forking and Ice Damage

Fusiform and forking were present in the stand with approximately 22 percent of the stems damaged by fusiform and approximately 20 percent having a fork. Although there were significant differences between the spacings for the occurrence of fusiform and forking, there appeared to be no pattern between fusiform and spacing and between forking and spacing. The initial hypothesis was that the density of spacing might affect the movement of the fusiform spores and thus cause differing infection rates. The 12x6 and 16x6 spacings had the highest infection rate while the 10x6 spacing had one of lower infestation rates and the 24X6 spacing had the lowest infection rate (table 2). Thus the hypothesis was rejected and there is no pattern in this stand for fusiform infestation. Forking appeared to be uniform among the spacings except for the 12X6, which had a significantly lower forking rate. However, this appears to be chance and no pattern was detectable.

Table 1—Height to limbs and diameter of live limbs in stands with different spacing densities

Spacing	Height First Live Limb	Height First Live Whorl	Height Diameter of	Diameter First Live limb
	----------Feet----------			Inches
12X8	1.15[b]	10.8[b]	13.1[bc]	0.82[bc]
12X6	1.22[b]	12.1[a]	13.4[b]	0.76[c]
10X6	1.36[a]	11.9[a]	14.8[a]	0.70[d]
16X6	1.35[a]	9.6[b]	12.9[c]	0.86[b]
24X6	1.16[b]	7.3[b]	9.9[d]	0.94[a]

Means followed by the same letter are not significantly different at the P<0.05 probability level.

Table 2—DBH, total height, fusiform, and forking occurrence and ice damage in stands of different spacing densities

Spacing	DBH	Height	Fusiform	Forking	Unsalvageable
	inches	feet	------------------Percent--------------------		
12x8	7.2[a]	36[a]	20	23	5
12x6	6.3[c]	32[c]	29	11	25
10x6	5.8[d]	34[b]	18	27	41
16x6	7.0[ab]	32[c]	29	20	7
24x6	6.7[b]	27[d]	14	20	2

Means followed by the same letter are not significantly different at the $P < 0.05$ probability level.

After the measurements were completed the stand was row thinned with individual selection within the rows (summer 2000) to bring standing density to 200 trees/acre or to a basal area of 50 to 60 $feet^2$/acre. In December 2000, two consecutive ice storms occurred in the thinned stands. The results were very dramatic. Trees in the two higher planting densities (10X6 and 12X6) were damaged significantly, 41 and 25 percent of the respective stems non-salvageable because of breakage of the main bole or extreme, non-recoverable bending of the main stem. Non-salvageable stems on the other three densities average five percent or less. Wider spaced trees had significantly larger diameters and apparently stronger central stems than the trees planted at the closer spacings. This resulted in the considerably less ice damage in the wider spaced stands, and these stands will continue to grow and produce whereas the high-density stands will have to be replaced.

CONCLUSIONS

Although these stands were originally designed for access in needle collection and poultry litter application, the different initial spacings and their growth provide some insight into the development of the various density stands. Generally, trees planted at wider spacings had shorter retained limb distance, larger limb diameter and larger tree diameters. The widest spacing (24x6) reduced height growth; trees had wider, shorter crowns and were generally rough in appearance. The two denser stockings (10X6 and 12X6) received severe damage in an ice storm, which suggests the central stems were weaker than trees in the wider spaced treatments. Overall the 12X8 spacing with 454 initial seedlings per acre had the best combination of traits measured. Trees in the 12X8 spacings had better growth, form, natural pruning and were more resistant to ice damage**.** This study does not support the common view that large numbers of trees (700-800) are required and necessary to adequately regenerate stands. It does support the concept of ensuring that strong trees make continuous fast growth with enough competition to enhance form but not cause weakened stand.

REFERENCES

Amateis, R. L.; H. E. Burkhart. 1996. Impact of heavy glaze in a loblolly pine spacing trial. Southern Journal of Applied Forestry. 20(3): 151-155.

Barns, B. V.; D. R. Zak; S. R. Denton; S. H. Spurr. 1998. Forest Ecology. New York: John Wiley and Sons, Inc. 774 p.

Belanger, R.P.; J. F. Godbee; R. L. Anderson; J. T. Paul. 1996. Ice damage in thinned and unthinned loblolly pine plantations infected with fusiforn rust. Southern Journal of Applied Forestry. 20(3): 136-140.

Smith, D. M.; B. C. Larson; M. J. Kelty; P. M. S. Ashton. 1997. The Practice of Silviculture: Applied Forest Ecology. New York: John Wiley and Sons, Inc. 537 p.

Wiley, S.; KB. Zeide. 1992. Development of a loblolly pine plantation. Arkansas Agricultural Experiment Station Report Series. 322 p.

DIAMETER GROWTH OF A SLASH PINE SPACING STUDY FIVE YEARS AFTER BEING THINNED TO A CONSTANT STAND DENSITY INDEX

Jamie C. Schexnayder, Thomas J. Dean, and V. Clark Baldwin, Jr.[1]

Abstract—In 1994, a 17-year old, slash pine (*Pinus elliottii* var. *elliottii*) spacing study was thinned to evaluate the influence of prethinning stand conditions on diameter growth after thinning. Diameter growth and crown dimensions measured just prior to thinning showed that diameter growth was positively related to both initial spacing and average crown dimensions. After thinning, these relationships almost immediately disappeared. The first year after thinning, diameter growth was significantly affected by only the initial 8 x 8-foot spacing treatment and was unrelated to prethinning crown dimensions. From the second to the fifth year after thinning, neither initial spacing nor prethinning canopy dimensions significantly influenced diameter growth. Within the fourth and fifth years after thinning, diameter growth appeared to become inversely related to prethinning crown dimensions, but the pattern was not statistically significant.

INTRODUCTION

Stand density is a major factor that a forester can manipulate in developing a stand. Foresters attempt to maintain stand density in a range that fully utilizes the site for maximum production of desirable, usable volume. By controlling stand density, silviculturists are able to influence species establishment, modify stem quality, rate of diameter growth, and volume production during stand development (Daniel and others 1979). In plantations, density is controlled through initial spacing of seedlings and with thinning. Silviculturists must make a compromise between individual tree growth and total stand growth when choosing appropriate planting spacing. At relatively close initial spacings, stand yields are usually highest, whereas individual tree growth is normally best at relatively wide spacings (Long 1985). Thinning is an important silvicultural practice for improving tree growth by redistributing growth and increasing the growth rates of residual trees. It also allows forest managers to select trees to which additional growth will be allocated.

Many stand density measures are considered expressions of the average area occupied or average area available per tree relative to some standard condition (Curtis 1970). Reineke's stand density index (SDI) (Reineke 1933) expresses stand density in terms of the equivalent number of trees in a stand at a standard diameter of 10 inches ($SDI = TPA (QMD/10)^{1.6}$ where TPA = number of trees per acre and QMD = quadratic mean diameter (inches) at breast height). Advantages of using SDI as a measure of stand density are that it is independent of site, age, and species and is easily calculated.

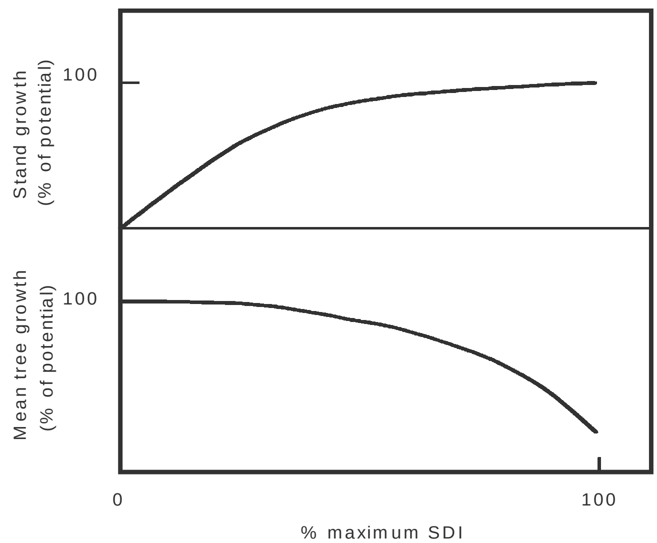

Figure 1—Hypothetical relationship between current annual growth and level of growing stock

Long (1985) illustrated the general relationship between current annual stand and individual tree growth as related to growing stock (figure 1). Relative SDI expresses growing stock relative to the species maximum SDI. The maximum SDI for slash pine is 450 (Dean and Jokela 1992). Since both stand and tree growths are functions of growing stock, stands of the same age and growing on the same site should have equal growth rates. When thinning is involved, however, potential tree growth is probably more strongly related to stand density prior to thinning for some time after thinning.

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The overall purpose of this research is to analyze the magnitude and the duration of the effects of prethinning stand conditions on diameter growth after thinning. With the expectation that plots thinned to a common SDI should exhibit the same growth rate, any differences in growth should be due to stand conditions prior to thinning.

METHODS

The study area is located about 1 mile east of Woodworth, LA, on the Alexander State Forest, which is managed by the Louisiana Office of Forestry. The soil is a Kolin silt loam with a clayey lower subsoil that restricts internal drainage. However, a slight slope in topography allows adequate surface runoff. This study was installed in the winter of 1976-1977 with planting stock from a single seed orchard of genetically improved parents. Seven spacing treatments (4 x 4, 4 x 6, 6 x 6, 6 x 8, 8 x 8, 10 x 10, and 14 x 14 feet) were randomly assigned to plots within five blocks. Each measurement plot consisted of 8 rows of 8 trees. A one-half chain (33 feet) isolation strip surrounded each measurement plot with trees of the same spacing.

At age 17, all plots within three of the blocks were thinned to 35 percent of the maximum SDI. Three of the spacing treatments were not included in this study. An ice storm shortly after thinning eliminated the 4 x 4 and 4 x 6 spacings from the study, and the 14 x 14 spacing was not used because the average stand density was too low for it to be thinned when the thinning treatments were applied. Additional information about the plots and the original study can be found in Ferguson and Baldwin (1995) and Baldwin and others (1995).

Trees were measured at age 15 years and before and after thinning at age 17 years. The trees were measured annually after thinning until age 22 years for five growth intervals after thinning. Field measurements consisted of diameter at breast height, height to live crown, total height, crown width in two directions at right angles, and crown class was also noted.

Diameter growth was analyzed for each age with a randomized complete block design. Correlation analyses were used to analyze the effect of initial spacing and prethinning crown dimensions on diameter growth after thinning using the simple correlation coefficient. Prethinning crown dimensions consisted of crown width (C_{W0}), crown length (C_{L0}), and crown ratio (C_{R0}). Crown width represents the span of the crown of a tree. Crown length represents the average length of the individual live crown. Crown ratio is the average ratio of crown length and total tree height per plot and is important in maintaining diameter growth and is related to stand density. All significant differences were tested at the 10percent significance level.

RESULTS

Average stand diameter growth of the trees for the different spacings at each age were compared (figure 2). Prior to thinning, diameter growth was strongly and negatively related to stand density. Initial spacing ceased to have any systematic effect on diameter growth the first year after thinning. While initial spacing significantly affected diameter

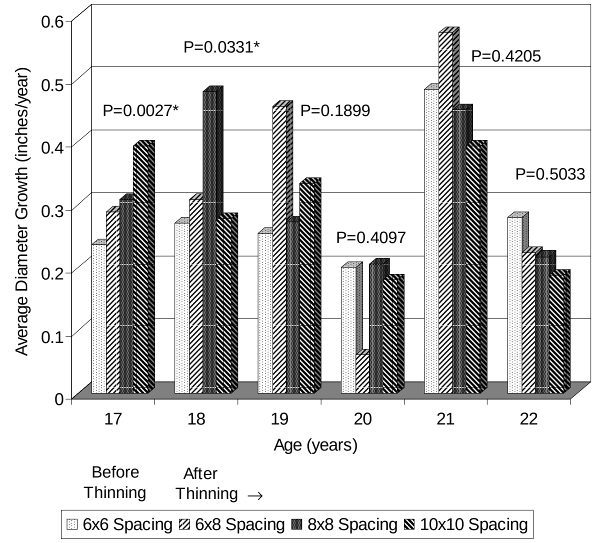

Figure 2—Average diameter growth for each spacing at age 17 before thinning and ages 18-22 after thinning for slash pine near Woodworth, LA

growth one year after thinning, the effect was due to the diameter growth in the 8 x 8-foot spacing. There was no significant difference in diameter growth between the 6 x 6, 6 x 8, and the 10 x 10-foot spacings the first year after thinning (figure 2). The influence of initial spacing on diameter growth diminished each year after thinning as evidenced by the increasing probability of a greater F value from age 19 to 22 years.

In addition to initial spacing, diameter growth before thinning was strongly related with crown size. Simple correlation coefficients between diameter growth and crown width, crown length, and crown ratio ranged from 0.81 to 0.86 (table 1). One year after thinning and thereafter, however, no correlation existed between diameter growth and crown size prior to thinning. Between the ages of 18 and 20 years, the simple correlation coefficients did not exceed 0.12 (table 1). Four and 5 years after thinning, the correlation

Table 1—Correlation coefficients relating initial spacing and prethinning crown width, crown length, and crown ratio to average mean diameter growth at age 17 (before thinning) and ages 18-22 (after thinning) for slash pine near Woodworth, LA

Correlation Coefficients (r)						
Age	17	18	19	20	21	22 p
C_{W0}	0.81	0.12	0.05	0.07	-0.37	-0.35
C_{L0}	0.86	0.01	-0.02	0.11	-0.33	-0.26
C_{R0}	0.84	0.12	0.06	0.07	-0.36	-0.39

coefficient became increasingly negative suggesting that diameter growth was becoming inversely related to initial spacing; however, the coefficients were not statistically significant (P > 0.20).

DISCUSSION

In general, results support the hypothesis that diameter growth is a function of growing stock and that stands thinned to a common level of stand density will have equal rates of diameter growth. Prior to thinning, average diameter growth was highest for the lowest stand density and decreased systematically with increasing density (figure 2). This trend is supported by the correlations between diameter growth and crown size for age 17 (table 1). The strong correlation between diameter growth, initial spacing, and crown size prior to thinning agrees with previous results (e.g., Curtin 1964, Smith and Bailey 1964, Hamilton 1969).

The effect of stand density on stem growth is generally considered to be through the effect of density on crown size. Since conifer crowns grow in size from the terminal buds, diameter growth was expected to be related to prethinning crown size for some time after thinning. However, the first year after thinning, the correlation between diameter growth and crown size that existed prior to thinning disappeared (table 1), and with the exception of the trees in the 8 x 8-foot spacing, initial spacing did not significantly influence diameter growth (figure 2).

Strub and Bredenkamp (1985) found that plots of loblolly pine (*Pinus taeda*) thinned late produced more total basal area than plots thinned early. Growth efficiency is generally inversely related to crown size (Jack and Long 1992), which together with the improved resource availability to the trees after thinning could be responsible for the rapid independence of diameter growth with initial spacing or prethinning crown dimensions. However, the absence of an initial spacing effect or relation to prethinning crown dimensions was not due to accelerated diameter growth in the more narrowly spaced plots; it was due to reduced diameter growth in the 10 x 10-foot spacing the first year after thinning followed by the trees in the 8 x 8-foot spacing the second year. If the combination of growth efficiency and greater resource availability results in more rapid diameter growth of the narrower initial spacings over that of the wider initial spacings, four years were required by these slash pine trees to manifest the effect. While not statistically significant, diameter growth four and five years after thinning generally decreased with increasing initial spacing (figure 2) and increasing prethinning crown size (table 1).

CONCLUSIONS

In general, the study shows that for these slash pine plantations (1) initial spacing significantly affected diameter growth prior to thinning but had little or no effect on diameter growth after thinning; and (2) the strong correlations between crown dimensions and diameter growth that existed prior to thinning disappeared when stands were thinned to a common stand density. These results suggest that prethinning stand conditions may eventually affect diameter growth, but for the first five years after thinning, the data are inconclusive.

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REFERENCES

Baldwin, V.C.; Dean, T.J.; Ferguson, R.B. 1995. A comparison of density indices in controlling growing stock in a slash pine spacing-thinning study.In: Edwards, M.B., comp. Proceedings of the Eighth biennial southern silvicultural research conference; 1994 November 1-3, Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 461-466.

Curtin, R.A. 1964. Stand density and the relationship of crown width to diameter and height in *Eucalyptus obliqua*. Austrailian Forestry. 28: 91-105.

Curtis, R.O. 1970. Stand density measures: An interpretation. For. Sci. 16: 403-414.

Daniel, T.W.; Helms, J.A.; Baker, F.S. 1979. Principles of Silviculture. New York: McGraw-Hill. 500p.

Dean, T.J.; Jokela, E.J. 1992. A density-management diagram for slash pine plantations in the lower coastal plain. Southern Journal of Applied Forestry. 16(4):178-185.

Ferguson, R.B.; Baldwin, V.C., Jr. 1995. Spacing effects on unthinned slash pine in the West Gulf Region. In: Edwards, M.B., comp. Proceedings of the Eighth biennial southern silvicultural research conference; 1994 November 1-3, Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 473-478

Hamilton, G.J. 1969. The dependence of volume increment of individual trees on dominance, crown dimensions, and competition. Forestry 49: 133-144.

Jack, S.B.; Long, J.N. 1992. Forest production and the organization of foliage within crowns and canopies. Forest Ecology Management. 46: 233-243.

Long, J.N., 1985. A practical approach to density management. Forestry Chronicles. 61: 23-27.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Resources. 46: 627-638.

Smith, J.H.G; Bailey, G.R. 1964. Influence of stocking and stand density on crown widths of Douglas-fir and lodgepole pine. Commonwealth Forestry Review. 43: 243-246.

Strub, M.R.; Bredenkamp, B.V. 1985. Carrying capacity and thinning response of *Pinus taeda* in the CCT experiments. South African Forestry Journal 2: 6-11.

HOW TO DETERMINE WHEN YOUR CONSERVATION RESERVE PROGRAM (CRP) PINE PLANTATION IS READY TO THIN

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Abstract—The CRP program was initiated in 1986 by the United States Department of Agriculture, Farm Services Agency, to protect topsoil from erosion. There have been 308,000 acres of CRP pine plantations established in Mississippi, and 1.2 million acres of CRP plantations have been established nationwide. Many of the CRP pine plantations in Mississippi will soon be ready for the first thinning. Timing and frequency of these first thinnings should be determined by site quality and landowner objectives. However, first thinnings are all too often considered to be a source of income for private landowners, and not a stand improvement tool. While income is a positive result, most landowners in Mississippi want to produce higher value sawlogs rather than low value pulpwood. Timing the first thinning too soon or too late can decrease site productivity and subsequent longer term financial returns for the landowner. The method presented here was developed to assist landowners and foresters in deciding when a first thinning should take place in CRP pine plantations in Mississippi. It is based upon five factors: 1) stand density, 2) natural pruning height, 3), average tree diameter, 4) heights of dominants and codominants, 5) and basal area growth rate. The decision of whether to thin or not is based on these characteristics, rather than on current pulpwood prices. This method provides a sound, unbiased means for foresters and landowners to decide the optimum time for the first thinning of young loblolly pine plantations.

INTRODUCTION

The Conservation Reserve Program (CRP) is the federal government's single largest environmental improvement program (USDA 1997). CRP was established in 1985 to provide participants an annual per acre rent, plus half the cost of establishing a permanent land cover (Dorell et al 1993). To date, approximately 308,000 acres of CRP pine plantations have been established in Mississippi with an average annual rental payment of $45 per acre for 10 years (Londo 2000).

Faculty in the Department of Forestry at Mississippi State University have developed a workshop to teach landowners the proper time to make the first thinning of their CRP pine plantation. This workshop shows them how to measure the following basic forest characteristics: average tree diameter, average tree height, stand density, height to natural pruning, and basal area growth rate. The workshop, as well as the recommended criteria for each measurement will be described.

WORKSHOP MECHANICS

The pine thinning workshops are held in individual counties in conjunction with each County Forestry Association (CFA) and Extension Agent. The first hour of the workshop is held indoors and serves as a lecture period. The lecture is usually given by one of the MSU Area Extension Foresters. The Area Extension Foresters are faculty members in the Department of Forestry and are responsible for conducting Extension forestry programs in their district of the state.

Information concerning pine growth and development, reasons for thinning, and method for thinning pine plantations are discussed. Following this lecture period, the landowners then go to a pine plantation to collect stand data.

With the assistance of forestry faculty and professional foresters, the landowners are broken into groups and disperse through the plantation for measurement collection. All measurements are collected within 100th acre plots. We encourage our participants to collect data on at least ten plots, scattered throughout the plantation. This is the minimum number of plots to get a good representative sample.

A double sampling technique is used to collect data. Plots are distributed systematically in a plantation using compass and pacing. The first sample is a 1/100th acre plot measuring DBH and trees per acre. Within each 1/100th acre plot, a single sample tree in the dominant or codominant crown class nearest plot center is measured for total

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Table 1—Basal area growth rate by DBH and 3-year radial growth. Bold numbers designate the threshold 10 percent annual rate of growth. Growth rates at or below the threshold indicate it is time to thin

DBH (inches)	3-year wood radial growth (inches)					
	0.3	0.4	0.5	0.6	0.7	0.8
		Basal Area growth rate (% per year)*				
5	**9**	12	15	18	21	25
6	7	**10**	12	15	17	20
7	6	8	**10**	12	15	17
8	5	7	9	11	13	15
9	5	6	8	**10**	11	13

* BA growth (%/year) = [(future BA – current BA) / (3 years * current BA)] * 100%
current BA = [current DBH]^2 * .005454
future BA = [current DBH + (2* radial growth)]^2 * .005454

height, pruning height, and basal area growth. The sample tree selected is also preferably free from any serious defect.

DBH is measured with a diameter tape and total height with a clinometer.

Natural pruning height (height to the first live limb) is measured using an 11 ft pole that is marked into 1-foot increments. Holding this pole, with your arm fully extended, will reach about 18 ft for most people. Lower pruning heights are easily determined by lowering the pole and counting the number of increments lowered. Stem radial growth (used to estimate basal area growth) is measured from an increment core collected at breast height.

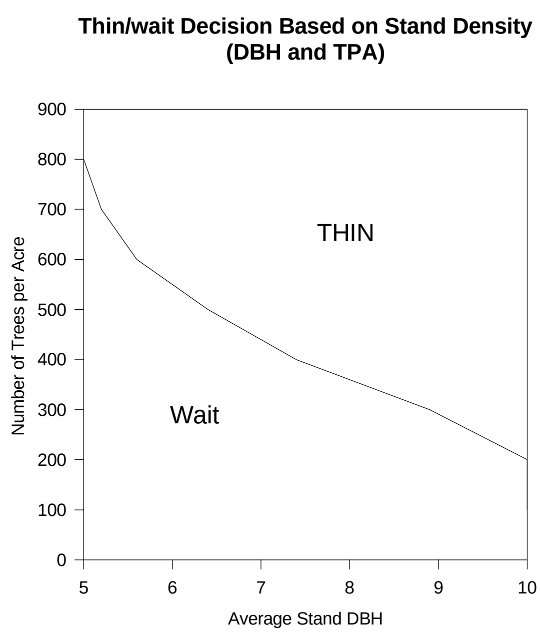

Figure 1—Thin/Wait decision based on 55% Stand Density Index (bold line) for young loblolly pine plantations.

Table 2—Pulpwood tons per tree for pines harvested during the first thinning. From: Jim McCreight. 1998. Unpublished data for Louisiana and Mississippi pine plantations

DBH (inches)	Total Height (feet)*		
	35	40	45
	Tons per tree		
5	0.029	0.030	0.032
6	0.061	0.064	0.068
7	0.095	0.100	0.107
8	0.133	0.140	0.150

* For young pines, merchantable height to a 3" top equals total height minus 10 feet.

A quick field estimate of future basal area growth is provided in table 1 using DBH and radial growth. Radial growth is measured from an increment core of wood taken horizontally through the central pith of the stem of the sample tree at breast height. Width of the growth rings for the last full three years is measured. Predicting future wood growth using past growth is "a reasonable postulate for a 3-5 year span" (Avery and Burkhardt 1994). Bark growth for the three-year period is assumed to be negligible. A simple interest rate was used because a straight-line best describes tree growth in young unthinned stands (Grosenbaugh, 1958). The calculations used to generate table 1 are:

Basal area (BA) is expressed in square feet per tree while DBH and radial growth are in inches.

current BA = [current DBH]^2 * .005454
future BA = [(future BA-Current BA)/(current BA)/(3 years)]*100percent
BA growth rate expressed as percent per year :
BA growth percent = [(future BA – current BA) /(3 years * current BA)] * 100 percent

DBH Measurements

Diameter at Breast Height (DBH) is important, because trees must be at least 5" DBH to be sold for pulpwood (Traugott 2000). Trees smaller than five inches DBH are not merchantable and typically won't be cut. Consequently, thinning plantations when only the larger trees are above this minimum size may result in high grading of the stand (Traugott 2000). We recommend at least an average tree diameter of six inches. Larger diameter trees also produce more volume, increasing the money earned by the land-owner at the time of thinning.

Other data may also be collected, such as the number of forked, diseased, or ice-damaged trees. Ice storms in 1994 and 1998 have damaged many pine plantations in North Mississippi. This information can be important for determining stand health and allowing for an informed decision on which trees to cut.

Table 3—Summary table for evaluating pine plantation characteristics measured in the field in order to determine whether plantation is ready to be thinned

Characteristic	Guideline	Ready for Thinning?		
Average DBH	≥ 6 inches	YES	Borderline	NO
Trees Per Acre				
Stand Density Index from figure1	≥ 55%	YES	Borderline	NO
Total Tree Height	≥ 40 feet	YES	Borderline	NO
Natural Pruning Ht	≥ 18 feet	YES	Borderline	NO
Basal Area Growth Rate	≤ 10%?	YES	Borderline	NO
What Do We Recommend?	THIN WAIT __ yrs			

Stand Density

The average tree DBH and number of stems per acre can be used to determine if the stand is dense enough to warrant thinning. Figure 1 shows a "thin – wait" decision line for loblolly pine. This line represents combinations of mean tree diameter and density that equate to 55 percent of the maximum Reineke's Stand Density Index value (SDI) for loblolly pine (Reineke 1933). Fifty-five percent of maximum SDI is where density-related mortality (self-thinning) can be expected to begin (Dean and Baldwin 1996).

A stand density index value of 55 percent was set as a general target rather than an absolute thinning criteria. Thinning a stand prior to this density may be desirable if a landowner is interested in maintaining high stand vigor and rapid individual tree growth. Delaying thinning beyond this density may be desirable if a landowner is willing to risk some mortality in order to capture a greater total stand volume yield. In addition to stand density index values, the decision of whether to thin or not must also take into consideration the other plantation characteristics discussed in this paper.

Tree Heights

Trees should be at least 40 feet tall for a plantation to be economically thinned (Traugott 2000). We are assuming that the top ten feet needs to be cut off to reach a 3-inch top. Logging operations in Mississippi typically use tree-length log trucks to haul trees from the woods to the mill. Merchantable stem lengths shorter than 30 feet create several problems for the logger. Double stacking short stems results in the truck being full of wood, but typically weighing less than the maximum haul weight of 25 tons (table 2). Higher hauling costs for short trees subsequently lowers stumpage prices for the landowner.

Natural Pruning

Since pines are shade intolerant, their branches die from the ground up as trees become crowded and over topped (Traugott 2000). Natural pruning needs to be at a minimum height of 18 feet. This 18 feet of natural pruning will result in a clear 16-foot butt log for future harvests. This is a much lower standard than the 24 ft reported by Nebeker et al (1986) which would achieve almost 1.5 clear logs.

Natural pruning is most important in the butt log since it is the largest and most valuable log in the tree. Live limbs produce knots in the wood, decreasing strength and subsequent value as lumber. Pruning can be used to achieve the same results, but most landowners do not have the time or money to invest in this kind of operation.

Thinning before natural pruning occurs will allow limbs to live longer and get larger in diameter. What could have been future quality sawtimber is pulpwood or at best low-grade sawtimber. Current prices in Mississippi show this to be a $20 to $30/ton loss in value, or $200-$300 per acre.

Basal Area Growth

One important factor that affects the best time to thin is basal area growth of individual trees. Basal area is the stem cross-sectional area at breast height. Slow growth in basal area is an indicator of poor tree health and increased risk of loss to southern pine beetles. Basal area growth is also an important financial measurement because it is closely related to volume growth (Wenger 1984).

A general target of 10 percent basal area growth is useful for field evaluations. The choice of an acceptable growth rate is a personal one. Landowners reinvesting thinning income at a rate of return above 10 percent will thin earlier. If low rates of return 5 percent or less are expected from reinvestments, landowners will thin later. In general, trees growing over 10 percent each year are producing enough wood to justify waiting to thin. Once basal area growth drops to 10 percent or less there is financial incentive to thin.

Evaluation of Data

At the end of the workshop, we summarize all the data collected and determine if the pine plantation is ready to thin. The format to summarize and evaluate the data collected during the workshop can be found in table 3. We base the decision of whether to thin the plantation on the five factors listed.

SUMMARY AND CONCLUSIONS

There are thousands of acres of CRP pine plantations in Mississippi that are approaching the time for the first thinning. Proper timing is the most important management decision landowners can make for their pine plantation. The first thinning sets the stage for the future productivity and value of the plantation.

The method presented in this paper for determining the timing of the first thinning in CRP plantations is based on stand diameter, density, total height, natural pruning height, and basal area growth. Threshold levels for each of these factors are provided to indicate the need for thinning. The decision of whether to thin or not is made with specific knowledge of these five stand characteristics, rather than on stand age, appearance, or pulpwood prices. This method is easy to use, straightforward, and can be used by landowners and foresters alike. Modifications for different regions in the south could be easily made based on growth rates and markets in those areas.

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REFERENCES

Avery, T. E.; Burkhart, H.E. 1994. Forest Measurements 4th Ed. New York, NY: McGraw-Hill, Inc. 408 p.

Dean, T.J.; Baldwin, V.C.; Jr. 1996. Growth in loblolly pine plantations as a function of stand density and canopy properties. Forest Ecology and Management. 82:49-58.

Dorell, T.E.; Straka, T.J.; Moulton R.J.. 1993. An economic analysis of federal forestry cost share allocations 1985-1992. Efficiency of allocation related to forest productivity, economies of scale, and type of forestry practice. P. 561-562. In: Proceedings of the Society of American Foresters, 1993 National Convention: 561-562.

Grosenbaugh, L. R. 1958. Allowable cut as a new function of growth and diagnostic tallies. Journal of Forestry 56: 727-730.

Londo, A.J. 2000. The effects of forest fragmentation on forest management for Mississippi private non-industrial forest landowners. In: Proceedings of the Forest Fragmentation 2000 Conference. Sampson Group Inc. Alexandria, Va: 116-118.

Nebeker, T.E.; Hodges, J.D.; Karr, B.K; Moehring, D.M. 1986. Thinning practices in southern pines-with pest management recommendations. Tech. Bull. 1703. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 36 p.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Resources. 46(7): 627-638.

Traugott, T.A. 2000. Are my CRP pine trees ready to thin? Mississippi State University, Extension Service. Publication 2260. 7p.

USDA 1997. The conservation reserve program. U.S. Department of Agriculture. Farm Services Agency PA-1603. 40 p.

Wenger, K. F. 1984. Forestry Handbook 2d Ed. New York, NY: John Wiley and Sons, Inc., 1335 p.